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ROUGH SURFACES AND RELIEF EXTRACTION BY GENERALIZED LAMBERTIAN'S PHOTOMETRIC MODEL

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ABSTRACT

Within the framework of the analysis of 3D textured environment through image analysis, we approach here the case of the rough surfaces for the analysis of the local variations of their relief. Generally, the interaction between the light and these local relief variations leads to a textured image of these surfaces. The proposed approach is an original stereovision adaptation based on photometric model to the case of surfaces with a high degree of roughness and with Lambert's photometric behaviour. Indeed, the usual approach treats only the case of surfaces with weak roughness, without consideration of the phenomena such as interreflexions, shades or still maskings between elementary facets of surface. We propose to take into account these phenomena through the adaptation of Oren-Nayar's model for the photometric stereovision. A comparative study is done to put out the contribution of the proposed approach in the case of rough surfaces.

1. INTRODUCTION

In this paper, we are interested in the local variation analysis of the rough surface relief in a fine scale. Generally, the surface roughness leads to a textured aspect of corresponding images. Currently, the surface roughness analysis is mainly made through tactile sensors or through laser sensors [1]. These sensors allow generally to estimate the surface roughness through the analysis of a series of monodimensional statements. In part their functioning (high time of measurement, resolution, reduced focal length, etc.), these various types of sensors do not allow to envisage a use on surfaces of important dimensions or to envisage their transposition towards an embarked system.

A roughness estimation by image processing could allow significant advantages such as the consideration of bidimensional information, the processing time, and the possibility to extend to the dynamic analysis. Few works in the literature deal with the textured surface roughness analysis by image processing [2]. These works make a roughness estimation through the extraction of the surface relief variations, according to the application, by systems exploiting the use combined by a camera and by a projection of a structured light [3] or a not structured light [4–8].

The relief extraction is then obtained by track deformation measurement of this structured light or by the exploitation of photometric models (case of the photometric stereovision systems). The proposed approach is an original extension for the local relief extraction by photometric stereovision. This extension being particularly adapted to the case of surfaces which can contain various roughness scales. The proposed method will then be applied to the analysis of the French road surfaces. We shall clarify in this frame our contribution for the phase image extraction of the relief, the process and obtained results.

2. RELIEF EXTRACTION

2.1. Relation between gray level, aspect and relief

To establish the link between image, relief and colour, the considered surfaces having no specular behavior, we choose to use a model Lambertian to translate their diffuse photometric behavior and to establish the link between the gray level, the piece of colour information and the piece of relief information. The various approaches by photometric stereovision developed in the literature exploit the usual Lambertian model [9]. This model allows to traduct the researched photometric behaviour under restrictive hypotheses which conduct to disregard phenomena of interreflections between elementary facets, shadowing and masking. These considerations limit the validity of this approach in the case of roughness surfaces with a distribution of weak slopes. In raison of vided application, we propose the exploitation of the generalization of the Lambertian model developed by Oren and Nayar [10] which allows to consider these various phenomena and to lead to a relief extraction by photometric stereovision adapted at the case of rough surfaces with important slopes.

For this, we consider a rough textured surface constituted of Lambertian micro-facets lighted under an incidence angle θ_i and observed by a sensor placed perpendicular to the surface plane (x, y) (cf. figure 1).

The different angles of the figure 1 are defined as :

- θ_i : angle of incidence with regard to the rough surface,
- φ : angle of incidence with regard to the facet,

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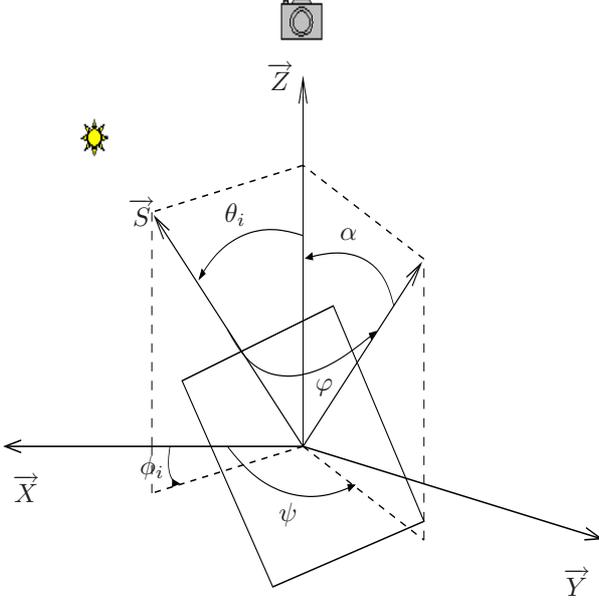


Figure 1. Illumination received by a sensor by a elementary part of surface.

- α : angle between the surface normal and the facet normal,
- ϕ_i : angle between \vec{X} axis and the projection of light source vector \vec{S} in the plane (\vec{X}, \vec{Y})

With a simple computation, we can so explain angle φ in function of cartesian coordinates (x, y, z) of the vided point.

2.1.1. The usual Lambertian model

In this case, intensity $I(x, y)$ in the gray level image traducts the energy received by the CCD sensor and it is written as:

$$I(x, y) = \frac{L(x, y)}{r^2} \cos(\phi(x, y)) \quad (1)$$

where $L(x, y)$ is representative of properties of aspect and colorimetry in each point of the surface and r the distance between the light source and the facet.

The term of luminance L can be expressed by:

$$L(x, y) = \rho \frac{I_0}{\pi} \quad (2)$$

where ρ represents the surface albedo and I_0 the light intensity of the source. From simple geometrical considerations, we then obtain the following equation:

$$I(x, y) = \frac{L(x, y)}{r^2} \times \frac{\cos \theta_i - \frac{\partial z}{\partial x} \sin \theta_i \cos \phi_i - \frac{\partial z}{\partial y} \sin \theta_i \sin \phi_i}{\sqrt{1 + \left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2}} \quad (3)$$

So the gray level in the image takes into account the piece of information bound respectively to the coloured aspect with the surface (L), to the local variations of its

relief ($\frac{\partial z}{\partial x}$ and $\frac{\partial z}{\partial y}$) in the acquisition configuration (θ_i) and the distance of the surface with regard to the camera (r^2). For the aimed application, distance r will be considered constant because it is superior to dimensions of relief variations which are of the order to some dozens microns.

2.1.2. The Oren-Nayar's model

To consider phenomena of interreflection, shadowing or masking, we exploit the works of M. Oren and S. Nayar [10] who propose a generalization of the Lambertian model for the rough surfaces of diffuse type, which could include relatively important lowerings. They model the important variations by V-cavities and clarifies the phenomena of interreflections and masking by, on one hand, a term additive and the usual Lambertian model and a term of attenuation allocated to the usual Lambertian model:

$$I(x, y) = \mathcal{GAF} I_L(x, y) + I_I(x, y) \quad (5)$$

where $I(x, y)$ represents the received total irradiance, the Geometric Attenuation Factor (\mathcal{GAF}) linked at the shadowing and masking phenomena, I_L is the usual Lambertian component and I_I the Lambertian component due to interreflection phenomena.

In the case of figure 1, the optical axis coincides with the surface normal. Therefore the expression of irradiance received by the CCD sensor can be written as:

$$I(x, y) = \rho \frac{I_0}{\pi r^2} \cos \phi + \rho^2 \frac{I_0}{\pi r^2} \cos \theta_i \cos \alpha (1 - \cos \alpha) \quad (6)$$

In this expression, the second term explains the effect of interreflections and maskings. We can so explain the equation 6 in function of the relief variations $p = \frac{\partial z}{\partial x}$ and $q = \frac{\partial z}{\partial y}$ by:

$$I(x, y) = \rho \frac{I_0}{r^2} \frac{\cos \theta_i - p \sin \theta_i \cos \phi_i - q \sin \theta_i \sin \phi_i}{\sqrt{1 + p^2 + q^2}} \quad (7)$$

$$+ \rho^2 \frac{I_0}{\pi r^2} \cos \theta_i \frac{1 - \frac{1}{\sqrt{1 + p^2 + q^2}}}{\sqrt{1 + p^2 + q^2}} \quad (8)$$

2.2. Principle of relief extraction method

We have previously presented the link between the relief, the colour appearance and its image in gray level. Equation 7 has three unknown variables; two variables characterize the surface geometry (the derivative of the altitude z with regard to x and those of the altitude z with regard to y) and the third characterizes the coloured aspect through the luminance $L(x, y)$. To determinate this three unknown variables, we exploit three images of our surface under different lighting configurations. We choose three different lighting configurations to obtain three linearly independent equations. From these equations, we express the surface variations through the partial derivatives of altitude z with regard to x and with regard to y . Then we obtain the relief $z(x, y)$ for all points of surface in using the numerical integration.

It exists various algorithm to obtain a tridimensional reconstruction from a gradient field [11–13]. For our application, we use the Frankot-Chellappa algorithm to integrate the partial derivatives [14]. The numerical integration from a gradient field consists to minimize a least square error function defined by the following equation:

$$W = \iint \left(\left(-\frac{\partial z}{\partial x} \right) - p \right)^2 + \left(\left(-\frac{\partial z}{\partial y} \right) - q \right)^2 dx dy \quad (9)$$

where $p(x, y), q(x, y)$ denotes the given non-integrable gradient field over this rectangular grid of image pixels.

Using the Parseval theorem, the minimization of the least square error function W allows to determinate a relation between the Fourier transform field of the surface and the Fourier transform of the gradient field [14]:

$$\hat{z}(u, v) = \frac{-iu\hat{p}^* - iv\hat{q}^*}{u^2 + v^2} \quad (10)$$

where $\hat{z}(u, v)$ is the Fourier transform of the surface and \hat{p}^* the conjugate Fourier transform of p . Also the surface can be obtain by the inverse Fourier transform of \hat{z} .

This algorithm is fast and easy to compute; therefore, it is limited to the surface reconstruction the gradient average value is equal to zero ($\hat{p}(0, 0) = \hat{q}(0, 0) = 0$)

3. EXPERIMENTAL RESULTS

3.1. Application field

The important development of road infrastructures requires to be able to have tools of auscultation and diagnosis of the state of roads. This auscultation is made in an objective of private assets management and safety of users. The concepts of safety bound to the road adhesion depend strongly on the geometrical shape of the layer surface and more particularly on the micro-roughness of the used aggregates.

The road degradation, bound to the road traffic, entails an evolution of the relief and thus the roughness of these aggregates. The study of this roughness in the finest scale, called microtexture is even today at the experimental stage. The measure of this scale is essentially based on profilometric methods [1, 15]. The disadvantages of these techniques, bound on one hand to the weak dimension of the analyzed sample and on the other hand in the acquisition time, do not allow to envisage eventually their transposition in an embarked system of auscultation. For that purpose, we are interested in the feasibility of this auscultation by a images processing system which could be later embarked.

3.2. Quantification of our approach

To compare the extracted reliefs for the two presented photometric models, we choose to make this comparison on a surface we can control the variations of relief and the slopes can vary in a significant way. The chosen surface is a surface with a cylindrical form. This choice is justified by the presence of all slopes on the type of form. The comparison of reconstructed reliefs with the usual Lambertian

model and with the Oren-Nayar’s Lambertian model is made with regard to a synthesis cylinder (cf. figure 2).

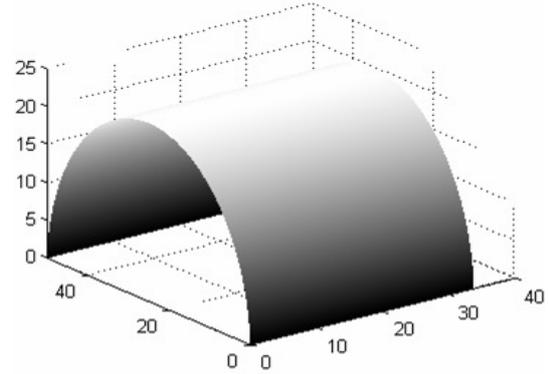


Figure 2. Synthesis cylinder using as reference to evaluate reconstruction errors.

From three acquisitions under different light source angles, we make the relief reconstruction from the two presented models (cf. figure 3).

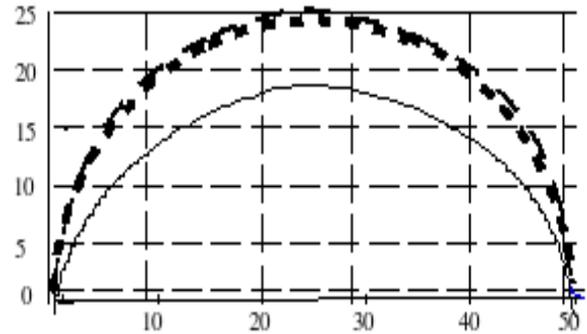


Figure 3. Profiles of reference relief (—), of reliefs reconstructed with the usual Lambertian model (---), with the Oren-Nayar’s model (- -).

The measurement precision, in both cases, is made by the error quadratic mean (EQM) and the noise to signal rate (NSR), the noise being constituted by the relative distance completely between the reconstructed relief and the reference relief. The results of these measurements are presented in the table 1.

	EQM	NSR (in %)
Usual model	1270.6	3.5234
Oren-Nayar’s model	78.4	0.1881

Table 1. Comparison of reconstruction errors.

Obtained results with phenomena of interreflection, masking are more precise than those obtained without these phenomena. It is more perceptible on the reconstructed profiles, for the strongest values of slopes. We shall adopt afterward the Oren-Nayar’s model for the height map reconstruction of our application field.

The relief extraction on all images of the various image bases was so made and an example of results is represented in figures 4. We represent image of the studied surface (figures 4(a)), the 3D cartography or corresponding height map (figure 4(b)) and the image of relief variations (4(c)).

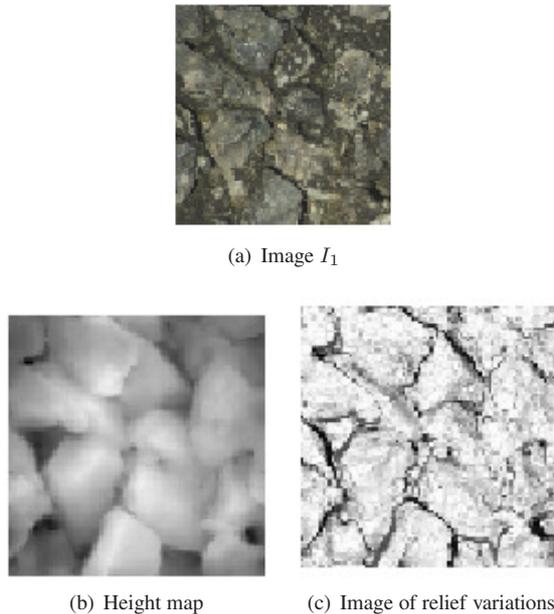


Figure 4. Three images of the studied surface, the corresponding height map and the image of relief variations.

4. CONCLUSIONS

We have introduced an approach to obtain a surface height map. The extraction of height map is made with photometric stereovision. From classic stereovision techniques, we develop an approach which considers the phenomena of interreflection, shadowing and masking existing on surfaces with strong roughness.

An estimation of roughness can be then led on the height maps extracted by image processing. The obtained results of roughness discrimination will allow to answer effectively the various objectives looked for in the analysis of the roads roughness. These works which were led on static rough surfaces are at present in the course of extension in the dynamic analysis of rough surfaces.

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